New Millennium Project (NMP)
Earth Orbiter-1 (EO-1)
Lightweight, Flexible Solar Array (LFSA)
Interface Control Document

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland

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Section 1. Introduction

This interface control document (ICD) defines the interfaces of the Lightweight, Flexible Solar Array (LFSA) to the Earth Orbiter-1 (EO-1) spacecraft, as well as the functional, physical, operating characteristics, and other requirements to meet the objectives of the experiment. This is the controlling interface document between the LFSA and the EO-1 spacecraft; therefore, the information contained herein supersedes in the event of conflicts with other applicable documents, including Interface Control Drawing A0757.

This ICD will serve as the controlling technical document between the LFSA and the EO-1 spacecraft. The document is controlled by the Goddard Space Flight Center (GSFC) EO-1 Project Office.

1.1 Applicable Documents

A0757	EO-1 LFSA Interface Control Drawing
AM-149-0020(155)	System Level Electrical Requirements NMP EO-1 Flight, Litton Amecom

1.2 Experiment Description

The LFSA is a category III experiment to be flown on the EO-1 spacecraft for the purpose of flight qualifying the following new technologies:

1. The copper indium diselinide/CuInSe2 (CIS) flexible photovoltaic (PV) cell and its interconnection into a solar array, mounted on a flexible substrate
2. A retention and deployment system of shaped-memory alloy
3. Hinge(s) of shaped-memory alloy

The LFSA will be manufactured by Lockheed Missiles and Space Corporation (LMSC) and provided by Phillips Laboratories.

Figure 1-1 is an abbreviated experiment configuration diagram, showing the major assemblies of the LFSA. All LFSA assemblies are mounted to the zenith-facing deck of the EO-1 spacecraft. The power generated by the LFSA is dumped into a resistor and is not connected into the spacecraft power system.

Table 1-1 is a physical summary of the LFSA experiment.

Mass Allocation

Mass allocation includes cabling and harnessing up to and including the remote services node (RSN), hard mounts, and contingency.

Volume Envelope

190 x 500-mm footprint on the zenith-facing deck of the spacecraft, and 50 mm height.

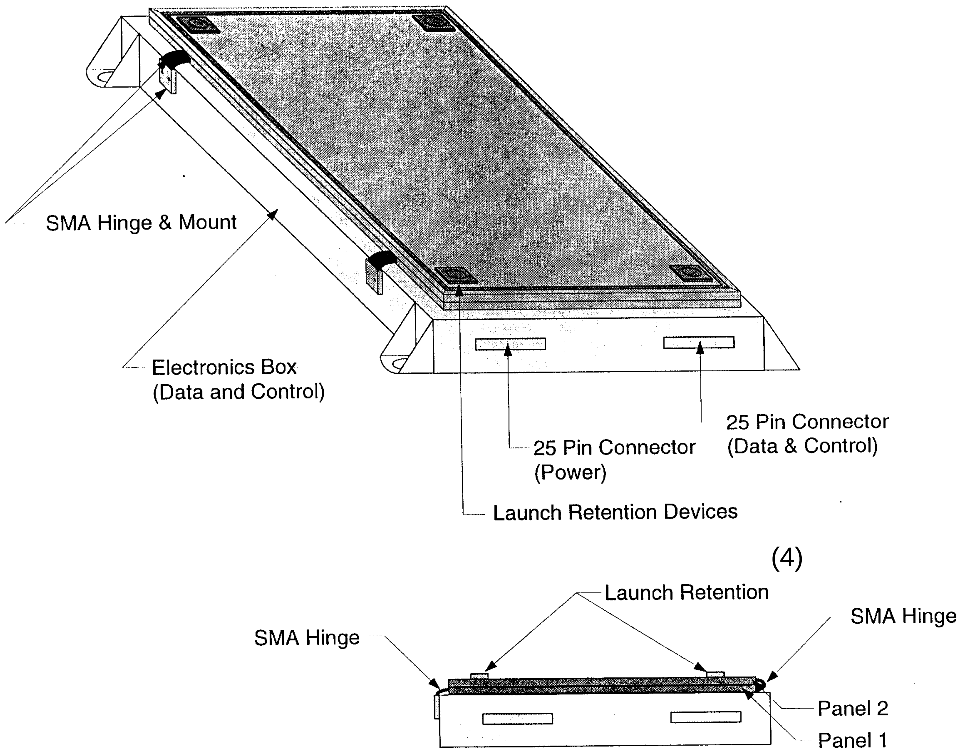


Figure 1-1. EO-1/LFSA Flight Experiment Configuration Diagram

Table 1-1. LFSA Physical Summary

Mass	≤ 5 kg
Natural frequency	≥ 0.2 Hz
Panel dimensions	19 cm x 50 cm
Stowed volume	4750 cm^3

Power Allocation

25 W peak (deployment)

2 W nominal orbit average

2.5 W for accelerometers (only on during jitter evaluation)

Assemblies

An interface box contains the electronics and the spacecraft mounting interface.

The concept is for the LFSA primary hinges to be connected to the interface box, and the interface box to be hard-mounted to the spacecraft. The location is on the zenith-facing deck above bay 3.

Primary Bus Voltage

28 +/- 7 V

Power Interface

28 VDC unregulated:	@ 2.5 A maximum
5 VDC regulated:	@ 0.8 A maximum(4 W)
15 VCD regulated:	@ 0.3 A maximum (4.5 W)
-15 VCD regulated:	@ 50 mA maximum (0.75 W)

Command

Launch restraint release command TTL (0 - 5 V)

Panel 1 deployment command TTL (0 - 5 V)

Panel 2 deployment command TTL (0 - 5 V)

Start command TTL (0 - 5 V)

Connection to Housekeeping RSN

One 25-pin connector J-2 command and telemetry, deployment power, LFSA electronics power

One 15-pin connector J-3 for tri-axial accelerometer power and telemetry

Telemetry Interface

3 TTL data channels:	0 - 5 VDC
5 analog data channels:	± 10 VDC
4 analog data channels:	0 - 10 VDC

Tri-Axial Accelerometer Interface

Input power:	+15 VDC and -15 VDC
TLM signal:	±10 V
Weight:	< 10 gr

Calibration Sources

NA

Temperature Interface

The allowed heat conduction between the LFSA and the spacecraft is 4 W.

Temperature Control

Operating temperatures: -20 to +80°C

Standby temperatures: -40 to 100°C

Survival temperatures: -40 to 100°C

1.2.1 Experiment Objectives

The LFSA sensor on EO-1 is designed to demonstrate advanced solar cell array technologies from a space platform.

1.2.2 Experiment Requirements

The CIS segment would be monitored and trended by mission operations. Voltage, current, and temperature readings would be sampled at a sufficient rate to characterize the solar panel performance and degradation throughout each orbit over the life of the mission.

The structural performance would be monitored during deployment with status switches.~~, and during orbital operations with LMA integrated accelerometer and ACS gyro output data.~~

Trend plots of the performance would be prepared monthly and must be coordinated with Ground Ops. Pseudotelemetry characterization of power would also be trended. Minimum, maximum, and average values of telemetry would be trended. This data would be made available to GSFC and Phillips Lab for analysis. Degradation would be compared to the performance prediction models.

1.3 Configuration

The LFSA configuration includes two interhinged, LFSA panels deployed from the zenith surface above bay 3. A nondeployable, electronics box will be attached to the spacecraft zenith surface below the LFSA as shown in Figure 1-3 (see also Figure 1-4 for the deployed configuration). Therefore, the LFSA, supplied by LMSC, will consist of a single package, containing three components, and the accelerometers:

- An outboard solar panel
- An inboard solar panel
- An interface box, containing the electronics and spacecraft mounting interface
- Tri-axial accelerometer
- Tri-axial accelerometer interface box containing the electronics

The concept is for the LFSA primary hinges to be connected to the interface box, and the interface box to be hard-mounted to the spacecraft.

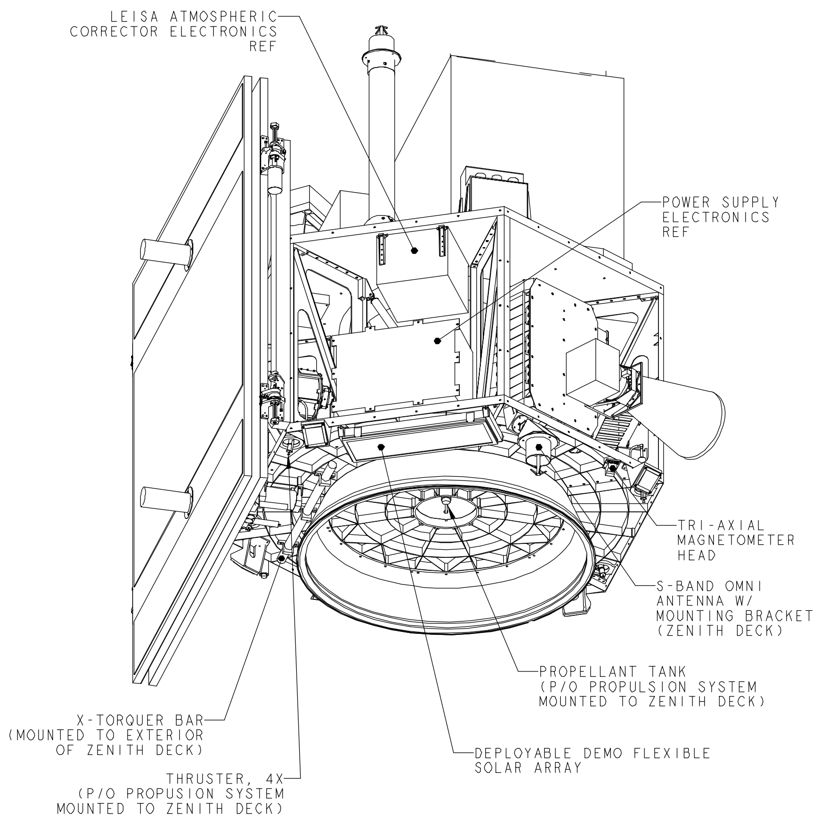


Figure 1-3. EO-1/LFSA Stowed Configuration

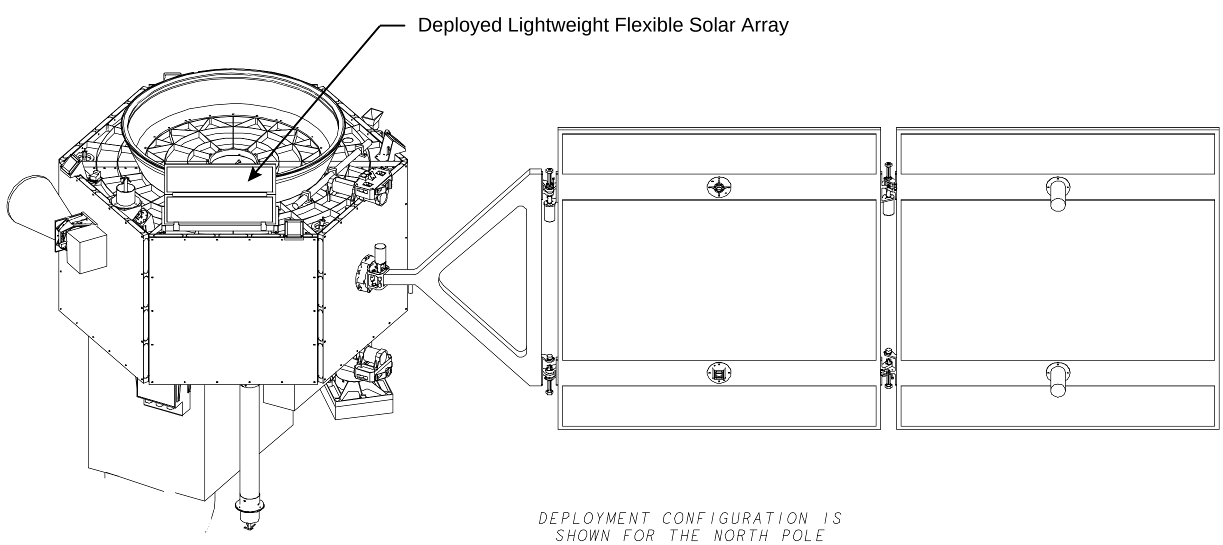


Figure 1-4. EO-1/LFSA Deployed Configuration

1.4 Experiment Objectives

The LFSA experiment consists of a flexible CIS blanket suspended in a composite frame. The frame is deployed using shape memory hinges and a launch restraint device.

The overall objective of the experiment is to demonstrate "soft" deployment of a solar array with >100 W/Kg efficiency.

Based on this, specific experiment objectives have been divided into those that pertain to shape memory mechanisms and those that evaluate CIS under on-orbit conditions.

1.4.1 Controlled LFSA Deployment

Required data:

1. Launch restraint status: Binary switch that indicates that the LFSA is released.
2. Deployment status: Two binary switches that indicate that the LFSA is fully deployed.

Approach: Use shaped-memory actuation to release launch retention mechanism followed by activation of shaped-memory hinges.

Anticipated results: "Soft" LFSA deployment into on-orbit position.

I and T: Ground testing will include functional testing of deployment system prior to and following thermal cycling, vibration and acoustic environment exposure. Shaped-memory actuator reliability and reproducibility will be evaluated during cyclic functional testing.

Rationale: Correlation between ground test results and expected LFSA behavior will be used to validate the objective. On-orbit data will be used to quantity SMA deployment behavior.

~~1.4.2 Jitter Evaluation~~

1. ~~Required Data~~
   a. ~~Experiment acceleration measured on two axes.~~
   b. ~~Spacecraft reference acceleration measured on 3 axes.~~
   c. ~~Temperature of flexible substrate - this is needed to derive tension of the substrate~~
2. ~~Approach: Evaluate dynamic properties of deployed LFSA several times during the mission.~~
3. ~~Anticipated Results: Jitter suppression associated with solar array flexibility. LMA is currently designing the LFSA with a natural frequency of 0.2 Hz or better.~~
4. ~~I and T Data: Develop finite element models that describe the dynamic properties of LFSA. These will be verified with dynamic tests conducted on representative demonstration articles at LMA.~~
5. ~~Rationale: Correlation of model results to on-orbit behavior. Development of scaling laws that allow full size LFSA behavior to be predicted.~~

1.4.2~~3~~ Thin Film Flexible CIS PV Performance Evaluation

Evaluate the thin film CIS PV combined environment on-orbit response, including

1. Thermal vacuum
2. Thermal cycling
3. Radiation and atomic oxygen

Required data/necessary measurements:

1. Array voltage
2. Array temperature
3. Solar insulation
4. Natural radiation and atomic oxygen levels

Approach: The CIS segment will be monitored and trended by mission operations. Array current, voltage, and temperature analog data will be telemetered and used for performance/degradation assessment. The solar insulation will be either monitored by the primary solar array instrumentation or interfered from the primary array electrical performance. Both the natural radiation and atomic oxygen levels will be calculated based on the orbital parameters and the industry standard environment models.

Anticipated results: Verification of the thin film CIS under actual on-orbit combined environment response.

Supporting I & T data: Flight array current-voltage (I-V) performance and continuity will be measured prior to integration with the solar array structure and integration with the spacecraft. Ground tests of the thin film CIS PV blanket structural and electrical interfaces as a function of temperature will be demonstrated in ground testing.

Rationale: The results of this flight experiment will validate the on-orbit response of an integrated thin film CIS array response and provide validated models for future spacecraft power system design.

1.5 Mechanical System Interfaces

Size: 190W x 500L x 50T mm

The LFSA experiment consists of the two interhinged solar arrays and the interface box. The LFSA is a self-contained mechanical assembly that contains all the experiment hardware, optical elements, and electronics. The experiment is mounted on the zenith-facing deck of the spacecraft. The experiment components have installations that make removal or repairs possible with the experiment installed on the spacecraft.

1.5.1 Coordinate System

The coordinate system is shown as per drawing A0757. This drawing also shows the location of the accelerometer.

1.5.2 Mounting Interface

The LFSA is hard mounted to the spacecraft on the zenith-facing deck as per drawing A0757.

1.5.3 Natural Frequency

Stowed: ≥80 Hz

Deployed: ≥0.2 Hz

1.5.4 Design Load

Steady State: 15 G's secondary structure in any direction

See Table 1-2 for random vibration test levels.

Table 1-2. Random Vibration Test Levels

Frequency (Hz)	Level	
	Acceptance	**Protoflight**
20	0.006 g^2/Hz	0.011 g^2/Hz
20 - 100	+6 dB/octave	+6 dB/octave
100 - 500	0.14 g^2/Hz	0.28 g^2/Hz
500 - 2000	-6 dB/octave	-6 dB/octave
2000	0.009 g^2/Hz	0.018 g^2/Hz
Overall	10.64 grms	15.04 grms

NOTES:
1. Levels are for each of three orthogonal axes, one of which is normal to the mounting surface.
2. Levels are to be applied at the interface with the EO-1 spacecraft.
3. Test duration is 1 minute per axis.
4. The table shows flight acceptance and protoflight test levels. These levels may be reduced (notched) in specific frequency bands, with Project concurrence, if required to preclude damage resulting from unrealistic high amplification resonant response due to the shaker mechanical impedance and/or shaker/fixture resonances.
5. Flight-type attach hardware (including any thermal washers, etc.) shall be used to attach the test article to the test fixture, and preloads and fastener locking features shall be similar to the flight installation.
6. Cross-axis responses of the fixture shall be monitored during the test to preclude unrealistic levels.
7. During the test, the test article shall be operated in a mode representative of that during launch.

1.5.5 Mass Properties

1.5.5.1 Mass

The weight is 5 kg maximum (including harness, accelerometers, and connectors).

1.5.5.2 Center of Gravity

The center of gravity shall be within 2.52 cm of the center of the electronics box.

1.5.5.3 Moment of Inertia

Moment of inertia of the LFSA shall be calculated with 5 percent accuracy.

1.5.5.4 Fastener Capacity

Attachment to the spacecraft is provided by Swales Aerospace as shown in drawing A0757.

Section 2. Electrical Interfaces

An interface box will be located on the spacecraft zenith-facing surface. This panel shall be the interface for all power, data, and commanding between the LFSA and the spacecraft. The electrical interfaces are shown in Figure 2-1.

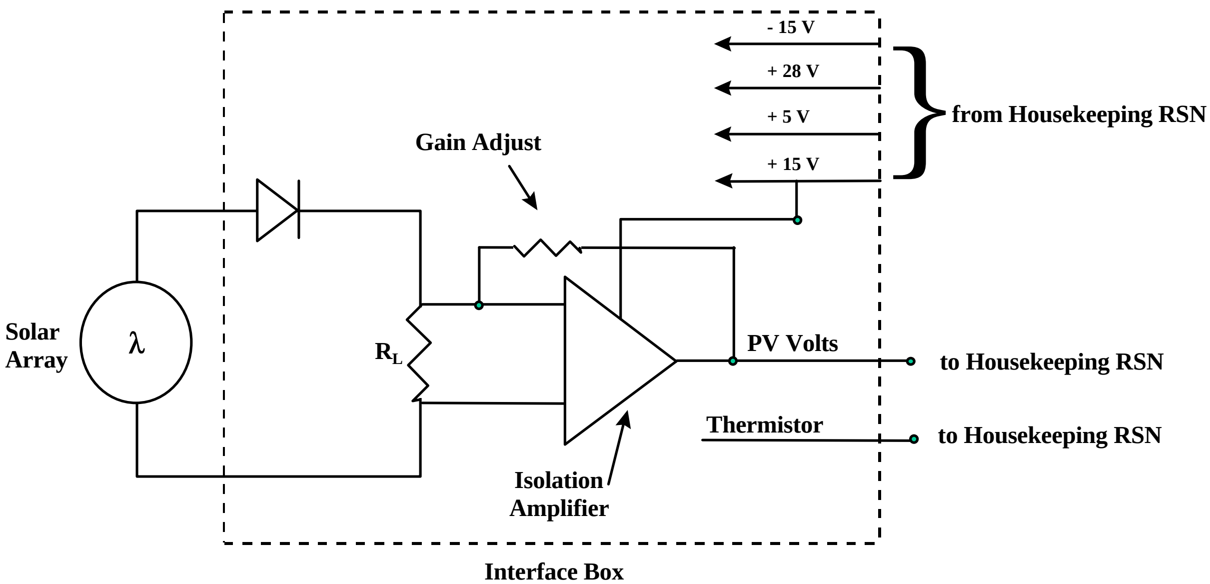


Figure 2-1. Interface Box~~xxxx~~

Each LFSA panel is treated as a separate array. The isolation amplifier interface configuration is listed in Table 2-1 below.

Table 2-1. Isolation Amplifier Interface~~xxxx~~

Item	Comment
Solar array location 1	Inboard panel
Solar array location 2	Outboard panel
Load r~~R~~esistors 1 and 2	In ~~I~~interface box
Isolation a~~A~~mplifiers 1 and 2	In interface box
Telemetry range for isolation a~~A~~mplifier 1 and 2 outputs	0 - 10 V

2.1 Electrical Interface Definitions

Power

The spacecraft operating bus voltage is 28 ± 7 V.

Signal Voltage:

Source: Interface box

Isolation amplifier

Hinge Heater Power:

Hinge heater power shall be ≤ 5 W per hinge and applied for no longer than 5 minutes maximum.

Hinge Heater Voltage:

Four individual lines of 28 V supply with returns for supply 1 and 3 and 2 and 4 are tied together.

Thermistors:

Item	Implementation
Number of thermistors	2 type 'S' lead configuration part #44906, GSFC-S311P18-06S7R6
Location 1	On inboard LFSA
Location 2	On outboard LFSA
Telemetry range	0 - 10 VDC

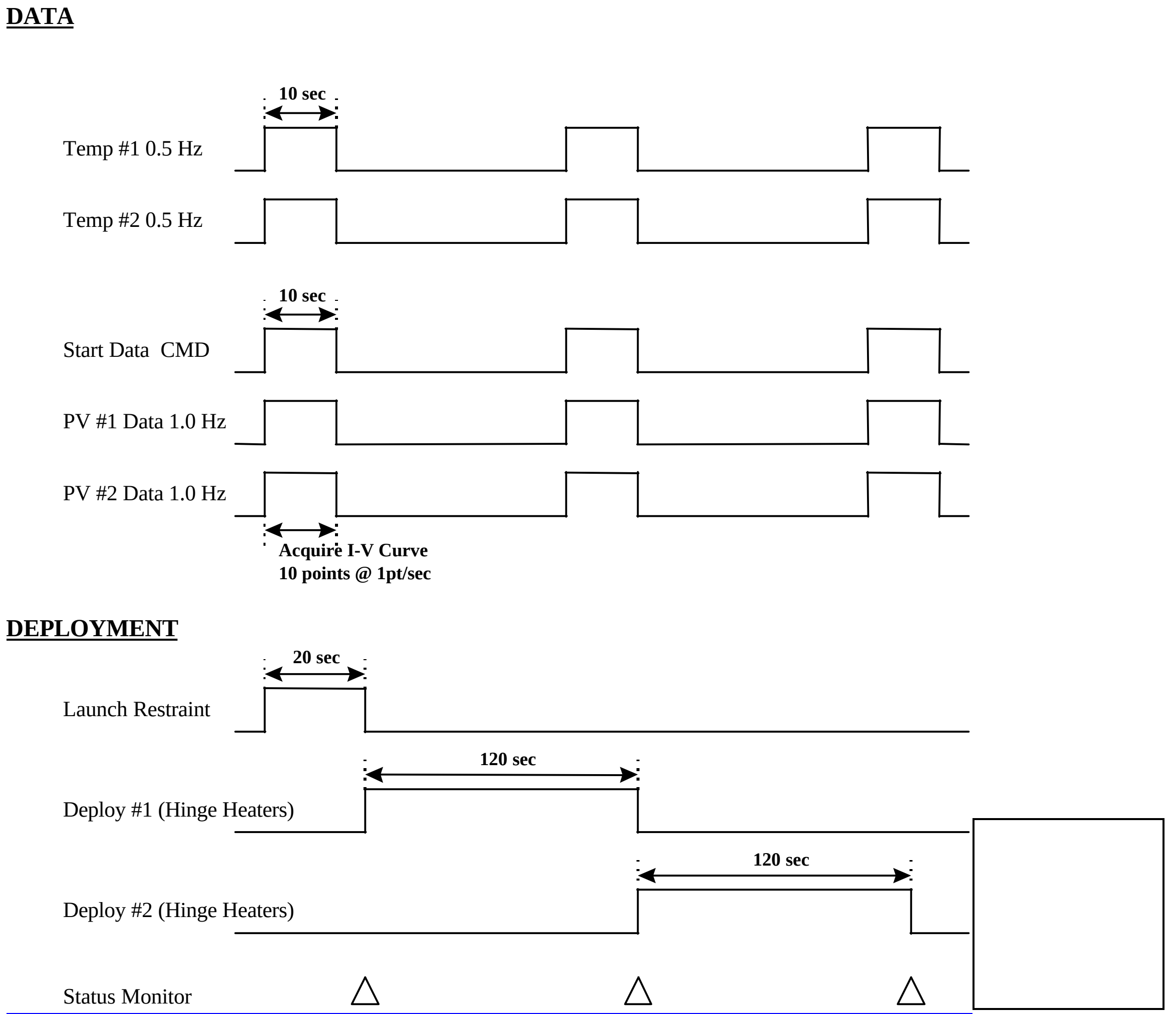
Position (Status) Indicators:

Item	Implementation
Number of switches	2
Location 1	On inboard LFSA
Location 2	On outboard LFSA
Location 3	Launch retention
Telemetry range	0 - 5 VDC binary

2.2 Timing Diagram for Data Events

LFSA Timing Diagram

The data collection and deployment command and status sequence is summarized in the timing diagram presented below. In addition, a more detailed description of these events is given in the text that follows.



Launch Restraint and Deployment

The launch restraint mechanism release is activated by an active high command issued from the spacecraft. Power is applied to the launch restraint actuator until the status switch is activated, which indicates that the launch restraint is fully released. Power is shut off to the launch restraint actuator based on the status switch or a timeout from the spacecraft software. It should take no longer than 20 sec to retract the launch restraint devices. The only data acquired during this time is the voltage from the status switches (1 point per 4 sec—0.25 Hz).

Following the 20-sec launch restraint period, the first hinge set is activated with an active high command issued from the spacecraft. The command remains high for 120 sec, during which time the hinges deploy. A status switch indicates that deployment has occurred but does not turn off the power to the hinge heaters. Power is turned off by a software timeout after 120 sec. Full deployment should occur within 60 to 90 sec. The only data acquired during this period is from the status switches (0.05 Hz).

The next event is deployment using the second set of hinges. Parameters are the same as above.

PV Data Collection

After deployment, the LFSA is suitable to acquire PV data from the CIS arrays. This data consists of acquiring an I-V curve at a temperature measured with the CIS blanket temperature sensors. At this time, it is also necessary to have knowledge of solar exposure either through the spacecraft Sun sensor or attitude.

PV data is acquired periodically throughout the mission according to the timing diagram. It is well known that CIS performance is temperature sensitive, and as such I-V data is acquired for three nominal temperatures (20-30°C, 40-50°C, and 60-70°C). The actual temperature that data acquisition starts is not critical, only that the temperature is known and that over the course of the spacecraft's life sufficient variation is provided to establish the thermal sensitivity of CIS. It is anticipated that these thermal variations can be induced by slewing the LFSA into direct Sun.

Data collection is initiated by a positive high pulse, 10 sec in duration. During this period, temperature data is acquired at 0.05 Hz. PV data is acquired simultaneously at the rate of 1 point per sec for a total of 10 points. The PV data is issued as a series of analog voltages that incrementally vary over the 10-sec period. PV data is periodically (once every 10 days) collected over the life of the spacecraft to determine environmental degradation of CIS in addition to its thermal characteristics.

2.3 Shielding

Wiring and cable assemblies, grounding, isolation, shielding, and radio frequency interference (RFI) enclosures shall be in accordance with *System Level Electrical Requirements NMP EO-1 Flight*, Litton Amecom document AM-149-0020(155).

2.4 Connector

All connectors not inside a shielded enclosure shall use EMI backshells to minimize radiation and susceptibility. 25-pin Cannon D connectors are preferred, as they are of a robust design which accommodates bonding an overall cable shield to the connector housing. Integral filter pins are allowed, but reliability must be considered. D-type connectors are allowed for data and control signaling connections.

J-1 LFSA/EO-1 Command and Telemetry Connector Pin Assignments

Pin #	Gauge	I/O	Name
5	24	O	Panel 1 temp
6	24	O	Panel 1 temp return
7	24	O	Panel 1 PV output positive
8	24	O	Panel 1 and 2 PV output negative
9	24	O	Status 1 output
10	24	O	Status 1 and status 2 ground return
11	24	I	28 V heater 1 supply
12	24	O	28 V heater 1 and 3 return
13	24	I	28 V heater 2 supply
14	24	O	28 V heater 2 and 4 return
16	24	O	Panel 2 temp
17	24	O	Panel 2 temp return
18	24	O	Panel 2 PV output positive
19	24	O	Status 2 output
20	20	I	28 V heater 3 supply
21	20	I	28 V heater 4 supply
22			Spare
23			Spare
24			Spare
25			Spare

J-2 LFSA/EO-1 Spacecraft Interface Connector Pin Assignments

Pin #	Gauge	I/O	Name	Voltage
1	24	I	Launch restraint command	+ 5 VDC active high
2	24	I	Deploy #1 command	+ 5 VDC active high
3	24	I	Deploy #2 command	+ 5 VDC active high
4	24	I	Start data acquisition command	+ 5 VDC active high
5	24	O	Temp 1	0 - 10 VDC
6	24	O	Temp 2	0 - 10 VDC
11	24	O	PV volts 1	0 - 10 VDC
12	24	O	PV volts 2	0 - 10 VDC
13	24	O	Status launch	+ 5 VDC deploy high
14	24	O	Status deploy 1	+ 5 VDC deploy high
15	24	O	Status deploy 2	+ 5 VDC deploy high
16	20	I	+ 28 VDC supply	+ 28 VDC
17	20	I	+ 28 VDC supply	+ 28 VDC
18	20	I	+ 15 VDC supply	+ 15 VDC
19	20	I	+ 5 VDC supply	+ 5 VDC
20	20	I	- 15 VDC supply	- 15 VDC
21	20	I	+ 28 VDC supply return	RTN
22	20	I	+ 28 VDC supply return	RTN

Pin #	Gauge	I/O	Name	Voltage
23	20	I	Common return	RTN
24	20	I	Common return	RTN
25	20	I	Common return	RTN

2.5 Isolation

When the experiment is disconnected from the spacecraft, the following circuits and returns shall be mutually electrically isolated by a DC resistance of at least 1 megohm: primary power, secondary power or signal; heaters; EED's or pyrotechnics; and shields/enclosures/structure.

Section 3. Deliverables

Item	From	To	Date
LFSA assembly	LM	Swales	30 June 98
Test procedures	LM	Swales	1 May 98
Connectors	Litton	LM	1 Jan 98

Abbreviations and Acronyms

^{o}C	degree Celsius
A	ampere
CIS	copper indium diselinide (CuInSe2)
cm	centimeter
cm^3	cubic centimeter
dB/octave	decibel per octave
EMI	
EO-1	Earth Orbiter 1
GSFC	Goddard Space Flight Center
g^2	
g^2/Hz	
gr	
grms	
Hz	hertz
ICD	interface control document
kg	kilogram
I&T	integration and test
I-V	current-voltage
LFSA	lightweight, flexible solar array
LMSC	Lockheed Missiles and Space Corporation
mA	milliampere
MHz	megahertz
mm	millimeter
NA	not applicable
NASA	National Aeronautics and Space Administration
NMP	New Millennium Program
PV	photovoltaic
RFI	radio frequency interference

RSN	remote services node
sec	second
SMA	
TTL	
V	volt
VDC	volt direct current
W	watt